Appendix A

Summary of Subsystem Including Components

The items that are designated as “optional” are not mandatory requirements. Some of those items may already be included in systems other than treatment, and therefore would be redundant. Other items, though desirable, are not mandatory. Automatic and semiautomatic operation is optional. Therefore, for each instrument and control item, though not indicated for clarity, there is an automatic option.

For Schematic Flow Diagram, see Figure A-1.

1. Raw Water Influent Main
   a. Flow control
   b. Flowrate measurement, flow total
   c. Preoxidation chemical injection for oxidation of As(III) to As(V)
   d. Excess preoxidation chemical removal
   e. Pressure indicators
   f. Pressure control (optional)
   g. Backflow preventer
   h. Sample before preoxidation chemical injection piped to sample panel
   i. Sample after preoxidation chemical injection piped to sample panel
   j. Sample after excess preoxidation chemical removal piped to sample panel
   k. Isolation valve
   l. Temperature indicator

2. Intervessel Pipe Manifold
   a. Process control valves
   b. Pressure indicator
   c. Sample piped to sample panel (optional)
   d. pH sensor, conductor, alarm
   e. Vessel 2 bypass valve

3. Treated Water Effluent Main
   a. Process control valves
   b. Chemical injection for pH adjustment(optional)
   c. pH measurement, indicator, alarm and fail-safe control
   d. Sample after pH adjustment piped to sample panel
   e. Pressure indicator
   f. Booster or repressurization pump (optional)
   g. Disinfection injection (optional)
   h. Isolation valve

4. Raw Water Bypass Main (optional)
   a. Flow control
   b. Flowrate measurement, flow total
   c. Backflow preventer
   d. Isolation valve

5. Backwash/Regeneration Feed Manifold
   a. Process control valves
   b. Isolation valves
   c. Backflow preventers
   d. Flow controls
   e. Flowrate measurements, flow totals
   f. Brine tank
   g. Brine eductor
   h. Brine injectors
   i. Pressure indicators
   j. Backflow preventors
   k. Sample brine eductor piped to sample manifold

6. Wastewater Main
   a. Process control valves
   b. Backflow preventers
   c. Process isolation valves
   d. Sight glass
   e. Sample piped to sample panel

7. Treatment Vessels
   a. Pressure vessel
   b. Treatment media
   c. Internal distribution and collection piping
   d. Pressure relief valve
   e. Air/vacuum valve
   f. Operating platform and/or ladder (optional)

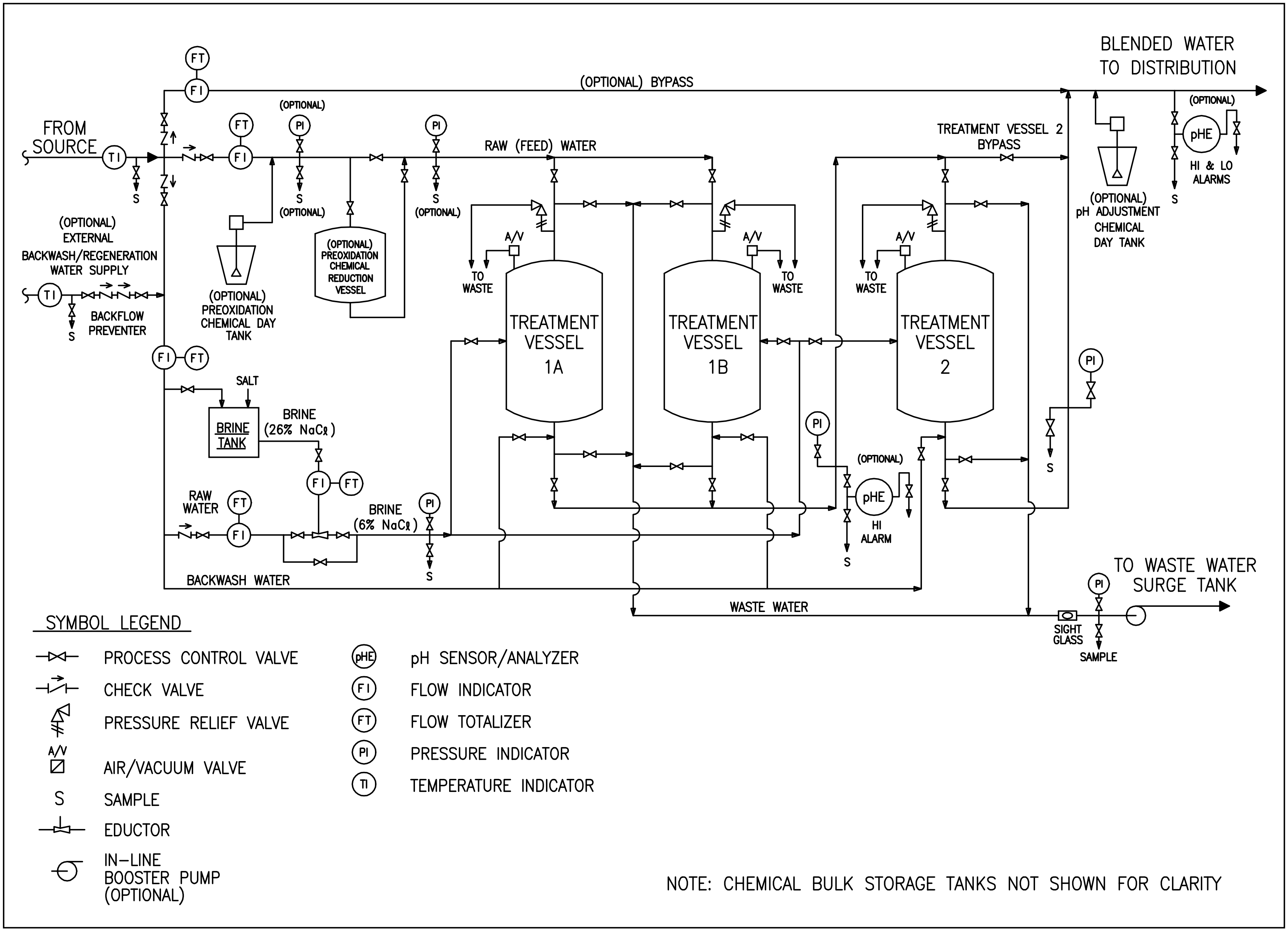

Figure A-1. Ion Exchange Treatment System Flow Diagram

8. Sample Panel (optional)
   a. Sample tubing from sample points with shut off valves
   b. Wet chemistry laboratory bench with equipment, glassware, reagents, etc.

9. Softener Salt Storage and Feed Subsystem
   a. Emergency shower and eyewash
   b. Softener salt storage tank (optional)
      i. Fill, discharge, and vent
      ii. Level sensor (optional)
      iii. Dust collection in vent
      iv. Weather protection
   c. Brine tank
      i. Water fill pipe with float valve
      ii. Softener salt feed pipe (optional)
      iii. Drain valve
      iv. Containment basin

10. Preoxidation Chemical Storage and Feed Subsystem (optional)
   a. Emergency shower and eye wash
   b. Preoxidation chemical storage tank outside treatment building (optional)
      i. Fill, discharge, drain, vent, and overflow piping
      ii. Liquid level sensor (optional)
      iii. Immersion heater with temperature control
      iv. Weather protection
      v. Containment basin (optional)
   c. Preoxidation chemical day tank (inside treatment building)
      i. Fill line float valve
      ii. Drain valve
      iii. Containment basin (optional)
   d. Preoxidation chemical piping (interconnecting piping)
      i. Between storage tank and day tank
      ii. Between feed pump and, feedwater main injection point
      iii. Backflow prevention

11. Backwash Water Disposal System (optional)
   a. Surge tank (optional)
   b. Unlined evaporation pond (optional)
   c. Sewer (optional)
   d. Drainage ditch (optional)
   e. Other discharge method (optional)

12. Toxic Regeneration Wastewater Disposal System
   a. Surge tank (optional)
   b. Wastewater reclamation system (optional)
   c. Other discharge method (optional)

Appendix B

Treatment System Design Example

This design example is applicable to a specific manually operated ion exchange arsenic removal water treatment system. This example is applicable to any of the following combinations of options:

1. Adjustment of EBCT
2. Adjustment of flowrate
3. Adjustment of arsenic concentration
4. Adjustment of raw water chemical analysis
5. Automatic operation in lieu of manual operation

Given:
q (flowrate) = 620 gpm
N (number of treatment trains) = 1
n (number of treatment vessels) = 3 (1A, 1B and 2)
Treatment vessel designations
  1A - Primary Stage - (operating)
  1B - Primary Stage - (standby)
  2 - Second Stage - (polishing)
Raw water arsenic concentration = 0.100 mg/L (0.002 meq/L)
Raw water sulfate concentration = 34 mg/L (0.68 meq/L)
Arsenic MCL = 0.010 mg/L
Treated water arsenic design concentration = 0.008 mg/L (max)
SBA resin manufacturer's published capacity = 1.016 eq/L (22,222 grains as $CaCO_3/ft^3$ or 50,930 g/m^3)
SBA resin removal capacity▫ = 0.915 eq/L (20,000 grains as $CaCO_3/ft^3$ or 45,838 g/m^3)
Salt consumption rate per regeneration = 10 lb/ft^3
EBCT = 3 min
M_d (media density) = 42 lb/ft^3
h(treatment bed depth) = 4 ft
$M_w = M_d \times V$ (media volume/vessel) × n (number of treatment vessels)
Treatment flowrate = 10 gpm/ft^2
Backwash flowrate = 4 gpm/ft^2
Brine flowrate = ½ gpm/ft^2
Pipe material - Type I Schedule 80 PVC, v (pipe velocity) = 5 ft/second (max.)
p (system pressure): 50 psig (max.)
T (ambient temperature): 95°F (max.)
T_w (water temperature): 85°F (max.)

1. Vessel and Treatment Bed Design (reference: Figure 3-3)

Solve for: d (treatment bed diameter)
V (treatment bed volume)
M_w (total weight of treatment media)
D (vessel outside diameter)
H (vessel overall height)

When EBCT = 3 min, then flowrate = 2½ gpm/ft^3 media

Then, when q = 620 gpm; then

$$V = \frac{620\ \text{gpm}}{2.5\ \text{gpm/ft}^3} = 248\ \text{ft}^3$$

Then, when h = 4 ft,

$$A = \frac{V}{h} = \frac{248\ \text{ft}^3}{4\ \text{ft}} = 62\ \text{ft}^2$$

Then,

$$d^2 = \frac{4A}{\pi} = \frac{4 \times 62\ \text{ft}^2}{\pi} = 78.94\ \text{ft}^2$$

Then, d = 8.89• = 8• 10½•

Then, D = d + 1• = 8• 11½•, therefore use D = 9• 0•

▫ 90% of manufacturer's theoretical capacity.

Then,

$$V = \frac{(8.92)^2 \times 5\pi}{4} = 250\ \text{ft}^3$$

Then, M_w = 3 × 250 ft^3 × 42 lb/ft^3 = 31,500 lb

Because the media quantity is almost a 40,000-lb truckload, it is prudent to procure a truckload quantity. That will provide an initial supply of makeup media.

Then the treatment vessel dimensions are as follows:

H = h + 0.9h + 4• + (2)D/4 + 1• =

$$48• + 44• + 4• + 2\left(\frac{108''}{4}\right) + 1• = 151• = 13•\ 1•$$

2. Pipe Sizing

Solve for: Sizes for water pipe mains

a. Raw and treated water mains:

q = 620 gpm (max)
Try 6•, v = 7.0 ft/sec › 5 ft/sec, therefore NG
Try 8•, v = 4.0 ft/sec › 5 ft/sec, therefore OK
Use 8• Schedule 80 PVC

b. Backwash pipe main:

q = 4 gpm/ft^2 × 62 ft^2 = 248 gpm
Try 4•, v = 6.2 ft/sec, therefore NG
Try 6•, v = 2.8 ft/sec, therefore OK
Use 6• Schedule 80 PVC

c. Brine (6% NaCl) pipe main:

q = 2 gpm/ft^2 × 62 ft^2 = 124 gpm
Try 3•, v = 5.3 ft/sec, slightly over 5 ft/sec - However low pressure, therefore OK
Use 3• Schedule 80 PVC

d. Concentrated brine (26% NaCl) pipe main

q = 0.2 × 2 gpm/ft^2 × 62 ft^2 = 25 gpm
Try 1½”, v = 4.0 ft/sec, therefore OK
Use 1½” Schedule 80 PVC

Note: During backwash of one treatment bed, the flowrate shall not exceed 250 gpm. Backwash rate is not to exceed rate required for 100% treatment bed expansion. This rate is sensitive to raw water temperature.

3. Softener Salt System Design

a. Storage Tank Size

Storage tank size is based on logistical requirements which are a function of treatment plant salt consumption rate and tank truck deliveries of granular softener salt. The tank truck can deliver up to 48,000 lb of softener salt.

In this example, the design treatment flow is 620 gpm, and it is assumed that the salt consumption is 1.33 lb/1,000 gal treated water. Then the salt consumption is 50 lb/hr, and a truckload would supply a minimum of 960 hours of treatment operation.

A commercially available “brinemaker” includes storage capacity for 72,000 lb, which provides capacity for 1½ bulk tank truckloads of salt. Therefore, when half a truckload is consumed, there is a minimum of a 450-hour (18.75-day) salt storage available before the salt supply is exhausted. In practice, it could be two times that minimum. The 36-ton storage capacity will easily maintain operation while awaiting delivery.

b. Day Tank Size

The “brinemaker” includes brine production (26% NaCl @ 40 gpm). A 1,200-gal brine day tank will satisfy the NaCl requirement for 1,875,000 gal of treated water, which exceeds the treatment flow for two days.

4. Regeneration Wastewater Surge Tank Design

Given:
Maximum volume of regeneration wastewater per cubic foot media = 150 gal/ft^3
Number of cubic feet of media per regeneration = 250 ft^3
Tank construction - epoxy interior lined carbon steel

Find:
Volume of wastewater per regeneration = 150 gal/ft^3 × 250 ft^3 = 37,500 gal = 5,000 ft^3
Dimensions of surge tank (use height = 16 ft)

Then,

$$(\text{diameter})^2 = \frac{4 \times 5{,}000\ \text{ft}^3}{\pi\, 16\ \text{ft}} = 398\ \text{ft}^2$$

Then, diameter = 20 ft

Then, tank dimensions = 20• ϕ × 16• h

Preferred Containment Basin Dimensions: length 40•, width 35•, height 4•, volume = 5,600 ft^3 = 42,000 gal >37,500 gal

5. Annual Regeneration Requirements

To appropriately plan operational labor, cost, and wastewater disposal requirements, the treatment system design shall determine the number of treatment vessel regenerations that will be required per year. Due to variation in seasonal demand for treated water, treatment cycle frequency increases during high consumption and decreases during low consumption periods. As described earlier in this manual, the treatment system is designed to treat at least 125% of the maximum consumption day. During low consumption periods the treated water requirement might be one third (or less) of the maximum consumption day. For purposes of this example, it is determined that the annual average utilization is 50%. Therefore, the treatment plant shall produce treated water 50% of the time on an annual basis.

Then, number of treatment vessel regenerations/ year equals:

$$\frac{\text{q (gpm)} \times 1{,}440\ \text{(min/day)} \times 365\ \text{(day/year)} \times \text{average utilization} \times (\text{As} + \text{SO}_4)\ \text{(mg/L)}}{\text{V}\ (\text{ft}^3) \times 90\%\ \text{removal capacity (gr/gal)} \times 17.1\ \text{(mg/L)/(gr/gal)}}$$

$$\frac{620\ \text{(gpm)} \times 1{,}440\ \text{(min/day)} \times 365\ \text{(day/year)} \times 0.50 \times 34.1\ \text{(mg/L)}}{250\ \text{ft}^3 \times 20{,}000\ \text{(gr/gal)} \times 17.1\ \text{(mg/L)/(gr/gal)}} = 65$$

or calculated using meq/L units:

$$\frac{\text{q (gpm)} \times 3{,}785\ \text{(L/gal)} \times 1{,}440\ \text{(min/day)} \times 365\ \text{(day/year)} \times \text{average utilization} \times (\text{As} + \text{SO}_4)\ \text{(meq/L)}}{\text{V}\ (\text{ft}^3) \times 28.3\ (\text{L/ft}^3) \times 90\%\ \text{removal capacity (eq/L)} \times 1{,}000\ \text{(meq/eq)}}$$

$$\frac{620\ \text{gpm} \times 3{,}785\ \text{(L/gal)} \times 1{,}440\ \text{(min/day)} \times 365\ \text{(day/year)} \times 0.50 \times 0.682\ \text{(meq/L)}}{250\ (\text{ft}^3) \times 28.3\ (\text{L/ft}^3) \times 0.915\ \text{(eq/L)} \times 1{,}000\ \text{(meq/eq)}} = 65$$

These calculations do not include any regeneration of the second stage treatment vessel. Any regenerations required of the second stage treatment vessel are in addition to the regeneration count of the first stage treatment vessel.

Appendix C

Tabulations of Estimated Capital Cost Breakdowns for Arsenic Removal Water Treatment Plants by Means of the Ion Exchange Process at Typical and Ideal Locations

Contents

Table C-1. Tabulation of Estimated Capital Cost[(a)] Breakdowns for Central Arsenic Removal Water Treatment Plants at Typical Locations by Means of the Ion Exchange Process with Manual Operation (Multiply by $1,000)

Treatment Flowrate (gpm)		65	115	230	330	480	555	620	700
Process Equipment									
Treatment Vessels		41	47	55	63	87	95	99	104
Ion Exchange Resin		22	37	62	79	96	117	127	138
Process Piping, etc.		17	17	32	34	34	41	45	45
Instruments and Controls		8	8	10	11	11	12	12	12
Salt and Brine Storage		3	3	5	5	5	20	20	20
	Subtotal	91	112	164	192	233	285	303	319
Process Equipment Installation									
Mechanical		28	29	34	36	36	44	45	45
Electrical		7	7	8	9	9	10	10	10
Painting and Miscellaneous		6	8	11	12	12	14	14	14
	Subtotal	41	43	53	57	57	68	69	69
Misc. Installed Items									
Wastewater Surge Tank		14	16	22	34	46	60	67	74
Building and Concrete		41	53	53	64	64	74	74	74
Site Work and Miscellaneous		12	13	14	16	16	17	17	17
	Subtotal	67	82	89	114	126	151	158	165
Contingency 10%		20	24	31	36	42	50	53	55
	Total	219	261	337	399	458	554	583	608

(a) August 2001 prices.

Note: Engineering, exterior utility pipe and conduit, wastewater and waste solids processing system, finance charges, real estate cost and taxes not included.

Table C-2. Tabulation of Estimated Capital Cost[(a)] Breakdowns for Central Arsenic Removal Water Treatment Plants at Typical Locations by Means of the Ion Exchange Process with Automatic Operation (Multiply by $1,000)

Treatment Flowrate (gpm)		65	115	230	330	480	555	620	700
Process Equipment									
Treatment Vessels		44	47	55	63	87	95	99	104
Ion Exchange Resin		22	37	62	79	96	117	127	138
Process Piping, etc.		42	43	70	74	74	82	88	88
Instruments and Controls		57	60	68	72	72	73	73	73
Salt and Brine Storage		3	4	5	5	5	20	20	20
	Subtotal	168	191	260	293	334	387	407	423
Process Equipment Installation									
Mechanical		31	32	37	40	40	49	50	50
Electrical		29	30	32	33	35	40	40	40
Painting and Miscellaneous		7	8	11	12	12	14	14	14
	Subtotal	67	70	80	85	87	103	104	104
Misc. Installed Items									
Wastewater Surge Tank		14	16	22	34	46	60	67	74
Building and Concrete		41	53	53	64	64	74	74	74
Site Work and Miscellaneous		12	13	14	15	16	17	17	17
	Subtotal	67	82	89	113	126	151	158	165
Contingency 10%		30	34	43	49	55	64	67	67
	Total	332	377	472	540	602	705	736	761

(a) August 2001 prices.

Note: Engineering, exterior utility pipe and conduit, wastewater and waste solids processing system, finance charges, real estate cost and taxes not included.

Table C-3. Tabulation of Estimated Capital Cost[a] Breakdowns for Central Arsenic Removal Water Treatment Plants at Ideal Locations by Means of the Ion Exchange Process with Manual Operation (Multiply by $1,000)

Treatment Flowrate (gpm)		**65**	**115**	**230**	**330**	**480**	**555**	**620**	**700**
Process Equipment									
Treatment Vessels		41	47	55	63	87	95	99	104
Ion Exchange Resin		22	37	62	79	96	117	127	138
Process Piping, etc.		17	17	32	34	34	41	45	45
Instruments and Controls		8	8	10	11	11	12	12	12
Salt and Brine Storage		3	3	5	5	5	6	6	6
	Subtotal	91	112	164	192	233	271	289	305
Process Equipment Installation									
Mechanical		25	26	31	33	33	41	42	43
Electrical		3	3	4	5	5	6	6	6
Painting and Miscellaneous		5	6	7	10	10	12	12	12
	Subtotal	33	35	42	48	48	59	60	61
Misc. Installed Items									
Wastewater Surge Tank		0	0	0	0	0	0	0	0
Building and Concrete		4	4	5	5	5	6	6	6
Site Work and Miscellaneous		0	0	0	0	0	0	0	0
	Subtotal	4	4	5	5	5	6	6	6
Contingency 10%		13	15	21	25	29	34	36	37
	Total	141	166	232	270	315	370	391	409

(a) August 2001 prices.

Note: Engineering, exterior utility pipe and conduit, wastewater and waste solids processing system, finance charges, real estate cost and taxes not included.

Table C-4. Tabulation of Estimated Capital Cost[a] Breakdowns for Central Arsenic Removal Water Treatment Plants at Ideal Locations by Means of the Ion Exchange Process with Automatic Operation (Multiply by $1,000)

Treatment Flowrate (gpm)		**65**	**115**	**230**	**330**	**480**	**555**	**620**	**700**
Process Equipment									
Treatment Vessels		41	47	55	63	87	95	99	104
Ion Exchange Resin		22	37	62	79	96	117	127	138
Process Piping, etc.		42	43	72	74	74	82	88	88
Instruments and Controls		57	60	68	72	72	73	73	73
Salt and Brine Storage		3	4	5	5	5	6	6	6
	Subtotal	165	191	262	293	334	373	393	409
Process Equipment Installation									
Mechanical		31	32	37	40	40	49	50	50
Electrical		34	35	37	38	40	45	45	45
Painting and Miscellaneous		5	6	7	10	10	12	12	12
	Subtotal	70	73	81	88	90	106	107	107
Misc. Installed Items									
Wastewater Surge Tank		0	0	0	0	0	0	0	0
Building and Concrete		4	4	5	5	5	6	6	6
Site Work and Miscellaneous		0	0	0	0	0	0	0	0
	Subtotal	4	4	5	5	5	6	6	6
Contingency 10%		24	27	35	39	43	49	51	52
	Total	263	295	383	425	472	534	557	574

(a) August 2001 prices.

Note: Engineering, exterior utility pipe and conduit, wastewater and waste solids processing system, finance charges, real estate cost and taxes not included.

Appendix D

English to Metric Conversion Table

English	Multiply by	Metric
inches (in)	0.0254	meter (m)
square inches (in^2)	0.000645	m^2
cubic inches (in^3)	0.000016	m^3
feet (ft)	0.3048	m
square feet (ft^2)	0.0929	m^2
cubic feet (ft^3)	0.0283	m^3
cubic feet (ft^3)	28.3	liters (L)
cubic feet (ft^3)	7.48	gal
equivalents/liter (eq/L)	21.8	Kgrains as $CaCO_3/ft^3$
gallons (gal)	3.785	liters (L)
gallons (gal)	0.0038	kiloliter (kL)
gallons (gal)	0.0038	m^3
grains (gr)	64.8	mg
grains (gr)	0.0649	grams (g)
grains/ft^3	2.2919	g/m^3
Kgrains as $CaCO_3/ft^3$	0.0458	eq/L
pounds (lb)	0.4545	kilograms (kg)
lb/in^2 (psi)	0.00689	megapascals (MP)
lb/ft^2 (psf)	4.8922	kg/m^2
c/1,000 (gal)	0.2642	c/1,000 L